UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Open-File Report 77-123

Prepared in cooperation with Energy Research
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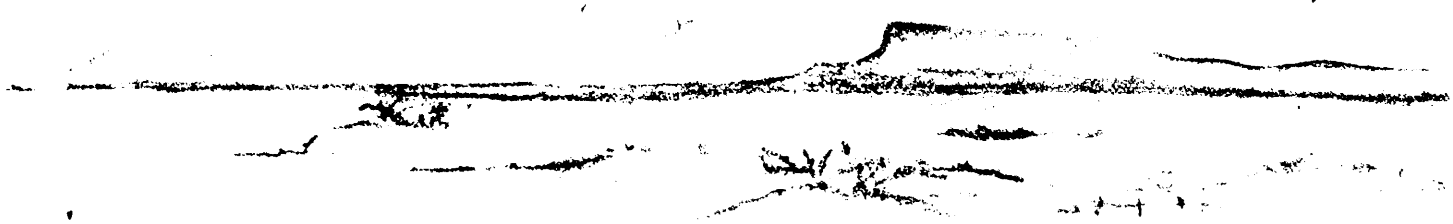

Review and Analysis of HYDROGEOLOGIC CONDITIONS Near the Site of a POTENTIAL NUCLEAR-WASTE REPOSITORY Eddy and Lea Counties, New Mexico

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By J. W. Mercer and B. R. Orr

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Albuquerque, New Mexico

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Illustrations

Tables

English to metric unit conversion factors

In this report figures for measurements are given in English units only. The following table contains conversion factors of the dual system of metric "The International System of Units (SI)" and English units:

English		Multiplied by	Metric	
Unit	Abbreviation		Unit	Abbreviation
feet	ft	.3048	meters	m
feet per mile	ft/mi	.1894	meters per kilometer	m/km
feet squared per day	ft^2/d	.0929	meters squared per day	m^2/d
feet cubed per day	ft^3/d	.0283	meters cubed per day	m^3/d
miles	mi	1.609	kilometers	km
gallons per minute	gal/min	.06309	liters per second	L/s
gallons per minute per foot	(gal/min)/ft	.2070	liters per second per meter	(L/s)/m

REVIEW AND ANALYSIS OF HYDROGEOLOGIC CONDITIONS NEAR THE

SITE OF A POTENTIAL NUCLEAR-WASTE REPOSITORY,

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By J. W. Mercer and B. R. Orr

Abstract

This interim report reviews and summarizes the hydrogeology of rocks associated with the Permian salt beds (Castile and Salado Formations) of Los Medaños area in southeastern New Mexico. The information will be considered, together with other factors, in the preparation of an analysis of the impact of a potential nuclear-waste repository on the environment.

Most of the geologic units in and adjacent to the Permian salt deposits are characterized by low permeabilities and highly mineralized water. Sandstone of the Delaware Mountain Group, which underlies the salt, has an average hydraulic conductivity of 0.16 ft/d and an average porosity of 15.65 percent. Flow is north-northeastward toward the margin of the Capitan Limestone, at velocities ranging from 0.0005 to 0.0008 ft/d.

The Capitan Limestone, a relatively high yielding limestone-reef aquifer adjacent to the study area, has been reported to have transmissivity values ranging from 500 ft^2/d to 10,000 ft^2/d and an average hydraulic conductivity of about 5 ft/d. Water movement west of the Pecos River is northeastward in the reef, with discharge at Carlsbad Springs. East of the Pecos River, water moves at very low rates and the direction of movement is uncertain.

The Castile and Salado Formations, which might be used to contain the nuclear waste, have a few isolated pockets of brine and gas, but generally transmit little or no ground water.

An evaporite residuum near the top of the Salado Formation was developed in localities where ground water has dissolved the upper Permian evaporites. Brine in the residuum moves southward along Nash Draw and discharges about 200 gal/min into the Pecos River at Malaga Bend. The transmissivity of the residuum is 8,000 ft^2/d and the flow rate is 0.2 ft/d.

The Rustler Formation overlies the Salado. The major water-bearing beds in the Rustler Formation are the Culebra Dolomite Member and Magenta Member, which in places are capable of yielding up to 700 gal/min. Values of transmissivity in the formation range from near 0 to 500 ft^2/d. The porosity and permeability in the dolomite is attributed to fracturing and to solution activity. Ground-water movement is south-southwestward toward the Pecos River.

Water in the Dewey Lake Red Beds, which overlie the Rustler Formation, occurs in sand lenses. Movement of water in the formation is restricted by low permeabilities.

The Santa Rosa Sandstone, overlying the Dewey Lake Red Beds, also has a low permeability. The porosity is about 10 percent and the rate of flow is 0.3 ft/d south-southwest toward the Pecos River.

Data on the occurrence of water in the Chinle Formation is sparce; however, its lithology indicates it would be a poor aquifer.

Other potential aquifers adjacent to the proposed repository area include the Ogallala Formation, Gatuna Formation, and alluvial deposits. Most water in the Ogallala moves to the southeast but some moves westward, recharging the Santa Rosa Sandstone aquifer. The Gatuna Formation contains water in sand and gravel lenses. Ground-water movement in the alluvium is in the approximate direction of surface flow of the Pecos River. An average value of transmissivity for the alluvium is 13,600 ft^2/d, and flow-velocity estimates are generally less than 1 ft/d.

Introduction

This report was prepared by the U. S. Geological Survey at the request of the Albuquerque Operations Office of the Energy Research and Development Administration (ERDA). It supplements the technical program of Sandia Laboratories, which is responsible for the investigation and possible development of the proposed nuclear-waste repository at Los Medaños (the Dunes) area east of Carlsbad, N. Mex.

The salt deposits of the Los Medaños area, Eddy and Lea Counties, New Mexico, have been studied since 1972 as a possible geologic unit for a waste-isolation repository pilot plant (WIPP). Geologic and hydrologic reports resulting from these investigations include primarily work done by the U.S. Geological Survey (USGS) for the Energy Research and Development Administration (ERDA). These and other studies are given in the list of selected references at the end of this report. This interim report reviews and summarizes existing data concerning the hydrogeology of rocks associated with the Permian salt beds. This information, together with that on other factors, will be used by Sandia Laboratories in the preparation of an environmental impact analysis. A later evaluation of data resulting from an extensive ongoing data-collection program will result in a more detailed report.

In 1957, the National Academy of Sciences National Research Council advisory committee recommended the use of bedded salt deposits as burial sites for solid nuclear wastes. The recommendation was based upon the hydrologic and geologic stability, plasticity, and favorable thermal characteristics of bedded salt.

The proposed site for the radioactive waste-disposal repository is in eastern Eddy County, 30 miles east of Carlsbad, N. Mex. in an area known as Los Medaños (fig. 1). The site encompasses the southwestern one-quarter of T.22 S., R.31 E. The Los Medaños area is part of a gently sloping terrain that rises eastward from the Pecos River to the "caprock" of the Llano Estacado. Topographic relief is generally less than 50 feet, and most geologic formations are covered with smoothly rounded hills of dune sand. Vegetation consists of mesquite, scrub oak, and other plants found in the northern Chihuahuan Desert. The annual precipitation averages 12 to 13 inches. Land use is primarily for cattle grazing. Potash deposits are presently being mined outside the area to the north and west, and some petroleum exploration and development has taken place in the area.

The Los Medaños area is drained by the Pecos River, a perennial stream with headwaters in north-central New Mexico. Most local tributaries originate in the Guadalupe Mountains. The Pecos drainage system trends southeast through the western margin of the study area. The drainage east of the Pecos, which includes the Los Medaños area, is very poorly developed.

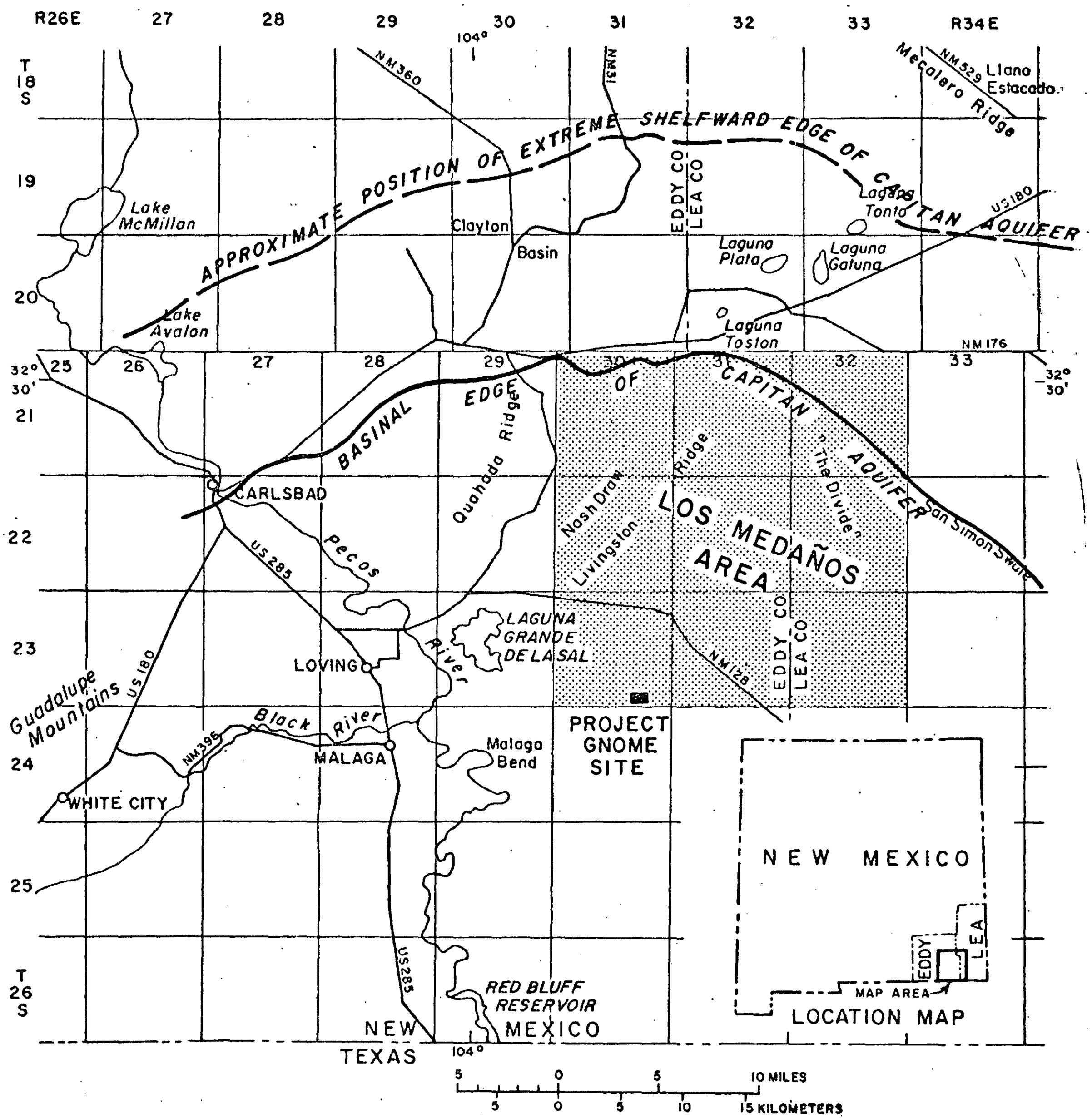


Figure 1.--Location map of Los Medaños area and vicinity.

The main topographic features in the vicinity of Los Medaños area were described by Brokaw and others (1972) and by Nicholson and Clebsch (1961). These features include the Guadalupe Mountains on the west, the Pecos River valley, the High Plains (Llano Estacado) and Mescalero Ridge to the east, and the pediment and alluvial plains that slope eastward from the Guadalupe Mountains and westward from the High Plains to the Pecos River (fig. 1). The study area is mostly on the pediment and alluvial plains east of the Pecos. Surface features formed by erosion have been modified extensively by solution subsidence and collapse. Locally, streams have exposed caliche and other rocks, but most of the area is mantled by dune sands. Some surface water drains eastward into closed depressions, but most of the precipitation is captured by sand dunes.

Laguna Grande de la Sal, a large salt lake in Nash Draw east of Loving, contains water most of the time. Numerous small lakes (lagunas and playas) contain water only after heavy rains. Small tailings ponds have been established in closed depressions as a result of potash mining. Lake McMillan and Lake Avalon north of Carlsbad, and Red Bluff Reservoir on the Texas-New Mexico state line, are the only large water bodies in the region.

The dominant solution depressions near Los Medaños area are Clayton Basin to the northwest, Nash Draw, which extends southward through the west-central part of the area, and San Simon Swale, which lies on the eastern margin (fig. 1). These features strongly affect the regional hydrology.

Hydrogeology

Regional setting

Late Permian limestones of the Capitan reef delineate the margins of the Delaware Basin where thick salt beds occur. The subsurface geology of the Delaware Basin includes rocks ranging from Precambrian to Quaternary in age. Precambrian crystalline basement rocks at depths up to 19,500 feet are overlain by approximately 14,000 feet of pre-evaporite Paleozoic rocks. Four thousand feet of Delaware Basin evaporites overlie these sedimentary rocks. Permian, Triassic, and Quaternary rock units are summarized in table 1.

The basin evaporites (Ochoan Series) were accumulated during Late Permian time (table 1). They include the Castile, Salado, and Rustler Formations. A thin red siltstone unit, the Dewey Lake Red Beds, overlies the evaporite sequence. East of Nash Draw along Livingstone Ridge, Triassic sandstone of the Santa Rosa Formation unconformably overlies the Dewey Lake Red Beds. Holocene caliche of the Mescalero surface and Holocene dune sand cap this Permian-Triassic stratigraphic sequence throughout much of Los Medaños area (fig. 2). The Pleistocene Gatuna Formation occurs as bolson-type deposits filling channels and steep-walled valleys (fig. 3).

Table 1.--Summary of rock units of Permian (Ochoan and Guadalupian) and younger age, Los Medaños area, Eddy and Lea Counties, New Mexico

Age			Rock Unit	Thickness (feet)	Description
Quaternary	Holocene		Sand of Mescalero surface	0-15	Dune sand, uniformly fine-grained, light-brown to reddish-brown
					UNCONFORMITY
Quaternary	Holocene		Alluvium	0-300	Sand, silt, and conglomerate
Quaternary	Holocene		Caliche	0-5	Limestone, chalky, includes fragments of underlying rock
					UNCONFORMITY
Quaternary	Pleis-to-cene(?)		Catuna Formation	0-375	Sandstone and siltstone, poorly indurated, dominantly reddish-orange
					UNCONFORMITY
Terti-ary	Mio-cene		Ogallala Formation	25-175	Sandstone, fine- to medium-grained, tan, pink, and gray, locally conglomeratic, and typically has resistant cap of well-indurated caliche
					UNCONFORMITY
Triassic	Late Triassic		Chinle Formation	0-800	Mudstone shaly, reddish-brown and greenish-gray, interbedded lenses of conglomerate, and gray and reddish-brown sandstone
Triassic	Late Triassic		Santa Rosa Sandstone	140-300	Sandstone, medium- to coarse-grained, commonly cross-stratified, gray and yellowish-brown, contains conglomerate and reddish-brown mudstone
					UNCONFORMITY
Permian	Ochoan		Dewey Lake Red Beds	200-600	Siltstone and sandstone, very fine to fine-grained, reddish-orange to reddish-brown, contains interbedded reddish-brown claystone, small-scale lamination and cross-stratification common
					UNCONFORMITY
Permian	Ochoan		Rustler Formation	200-600	Anhydrite and rock salt with subordinate dolomite, sandstone, claystone, and polyhalite
Permian	Ochoan		Salado Formation	1,450-2,073	Rock salt with subordinate anhydrite, polyhalite, potassium ores, sandstone, and magnesite
Permian	Ochoan		Castile Formation	1,300-2,000	Anhydrite and rock salt with subordinate limestone
Permian	Guadalupian	Delaware Mountain Group	Capitan Limestone	1,600±	Limestone, massive, with dolomitized reef breccia
Permian	Guadalupian	Delaware Mountain Group	Bell Canyon Formation	1,000±	Sandstone, brown and gray, with minor limestone and shale
Permian	Guadalupian	Delaware Mountain Group	Cherry Canyon Formation	1,000±	Sandstone, gray and brown, with limestone and minor shale
Permian	Guadalupian	Delaware Mountain Group	Brushy Canyon Formation	1,000±	Sandstone, gray, with brown and black shale and brown limestone

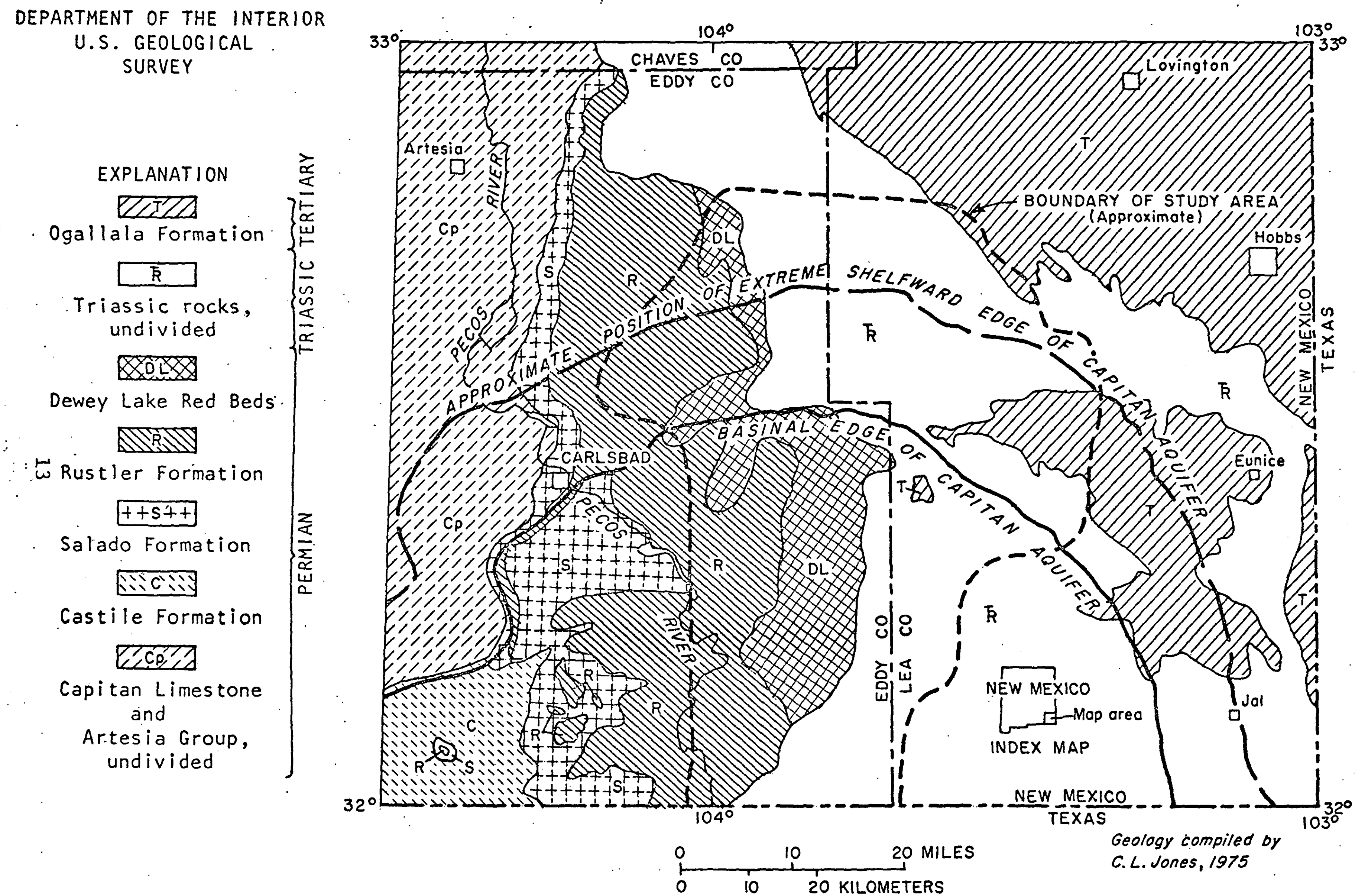


Figure 2.--Geologic map of Los Medaños area and vicinity.

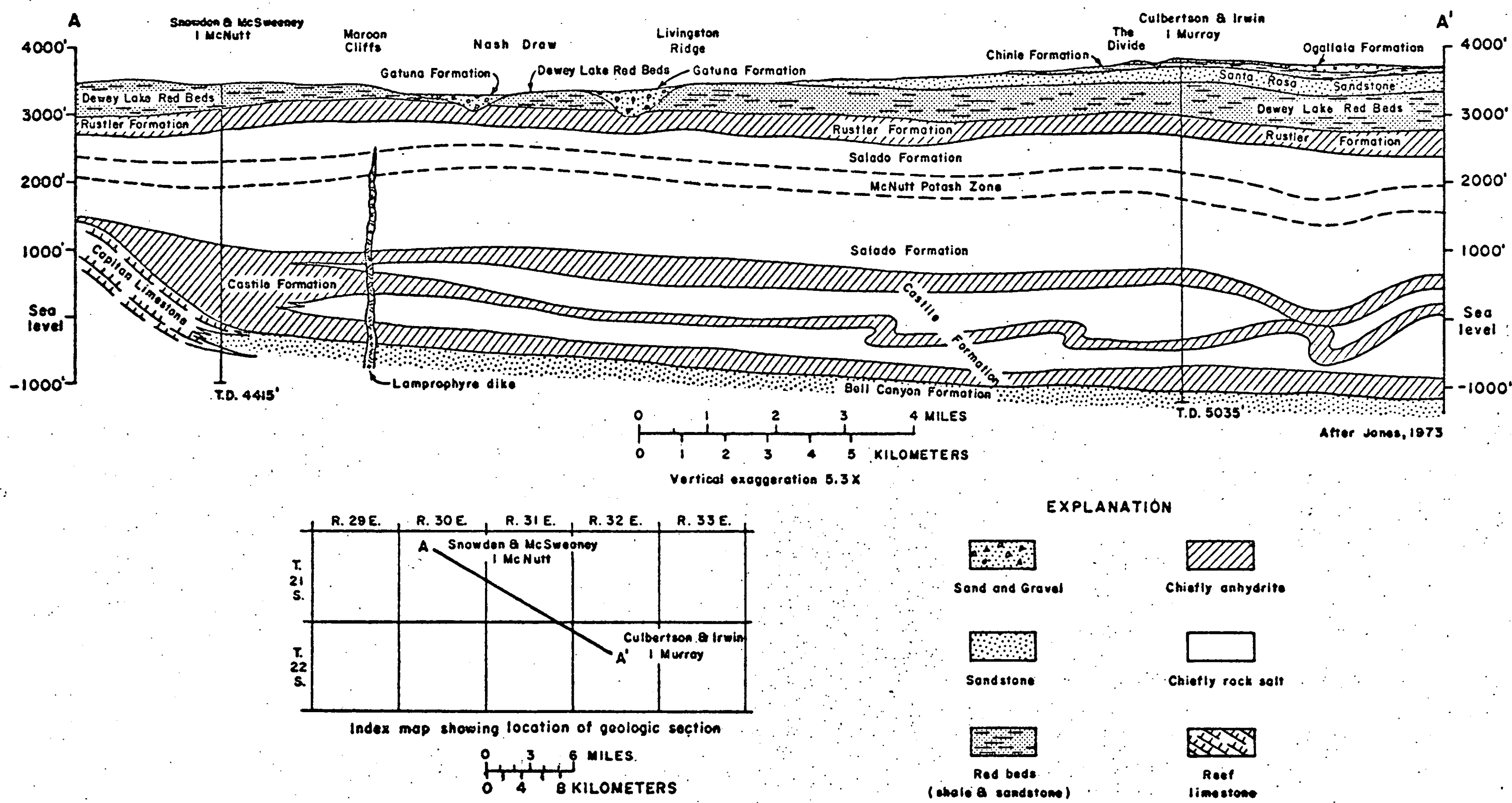


Figure 3.--Generalized geologic section of Los Medaños area.

Permian rocks

Delaware Mountain Group

The Delaware Mountain Group was subdivided by Richardson (1904) into (ascending order) the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations (King, 1942). The sandstone of the Delaware Mountain Group generally is encircled by shelf-margin carbonate rocks except for discontinuous beds of the Cherry Canyon Formation which interfinger with contemporaneous back-reef units of the San Andres Limestone on the Northwest shelf (Hiss, 1976, p. 94). Formations of the Delaware Mountain Group underlie the Capitan reef and form the basin floor for the Ochoan evaporite sequence.

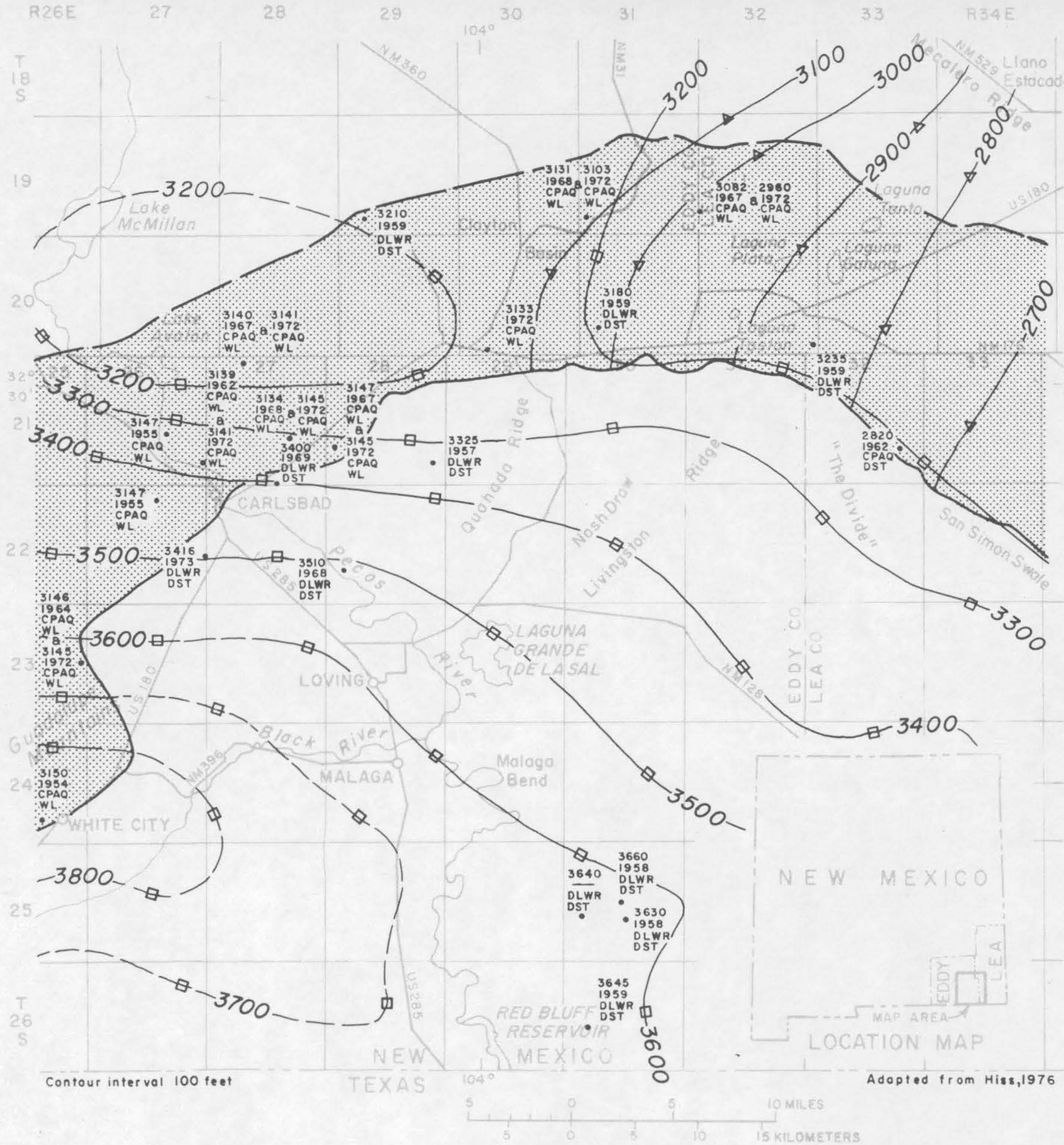
The Brushy Canyon Formation is the oldest unit of the group, consisting of about 1,000 feet of sandstone with occasional limestone lenses and, locally, basal conglomerate. Oil wells completed in this formation produce oil with highly mineralized water (Cooper, 1962, p. 19).

The Cherry Canyon Formation in the middle of the Delaware Mountain Group consists of about 1,000 feet of thin, fine-grained sandstone interbedded with continuous limestone units. The Cherry Canyon Formation in the Guadalupe Mountains yields water to wells and springs.

The Bell Canyon Formation, the upper unit of the Delaware Mountain Group, consists of approximately 1,000 feet of sandstone and thin limestone beds. The Lamar Limestone Member of the Bell Canyon Formation has produced some oil and highly mineralized water. In its outcrop area the Bell Canyon Formation probably yields water to springs near the base of the Capitan reef (Hendrickson and Jones, 1952, p. 13).

The Delaware Mountain Group, according to Hiss (1976, p. 206), has an average hydraulic conductivity of 0.016 ft/d and an average porosity of 15.65 percent. These values were determined by analyzing approximately 4,500 feet of rock core from the Delaware Mountain Group in Eddy and Lea Counties, New Mexico, and in Ward and Winkler Counties, Texas. Because of similar lithologies, it is assumed that the group acts as one aquifer system with an average saturated thickness of 3,000 feet. The calculated value of transmissivity for the Delaware Mountain Group is about 50 ft^2/d.

Hiss (1976) constructed a potentiometric map of the Delaware Mountain Group and the Capitan Limestone (fig. 4), after adjusting heads to a freshwater datum to account for variations in density. These variations, if not adjusted to a common datum, could greatly affect computations of the direction and magnitude of ground-water movement.



EXPLANATION

Position of Capitan aquifer — Approximate position of extreme shelfward edge; Basinal edge

△—△ Head measured in the Capitan aquifer and shelf aquifer system where the hydraulic communication between the two aquifers is relatively good.

□—□ Head measured in Delaware aquifer system where the hydraulic communication with the Capitan aquifer is relatively poor.

Contours of head, in feet above sea-level datum. Contours are dashed wherever data are sparse or of doubtful reliability.

The contours express a generalized regional head considered to be representative for the Delaware aquifer during the period 1960 to 1970. Similarly, contours in the Capitan aquifer are an interpretation of the head representative for the latter part of 1972.

Considerable subjective judgment was used in contouring the data points. In general, two factors were weighed in considering each data point:

(1) The year in which the head was measured: This is important because prior fluid withdrawal from the oil and water fields causes a decline in head in nearby areas.

(2) The reliability of the data: In general, the data were ranked according to reliability in the following order: fluid level in water wells, initial oil field bottom-hole pressures, and analysis of pressures from drill-stem tests.

Example: 3015 / 1960 / CPAQ / WL
- 3015 — Altitude of potentiometric surface, in feet above sea-level datum
- 1960 — Year in which data were measured
- CPAQ — Formation in which pressure or water level was measured (CPAQ = Capitan Limestone; DLWR = Delaware Mountain Group)
- WL — Type of measurement: BHP - Bottom-hole pressure, DST - drill-stem test, WL - water level
- ● — Well penetrating sedimentary rocks of Permian, Ochoan, Guadalupian, or Leonardian age

Figure 4.--Adjusted potentiometric surface of the Delaware Mountain Group and Capitan Limestone. (Values of head are expressed as water with specific gravity of 1.00.)

The hydraulic gradient of the potentiometric surface for the Delaware Mountain Group ranges from 25 to 40 feet per mile. Southwest of Carlsbad, Delaware Mountain Group water probably discharges into the Capitan Limestone and mixes with eastward-moving Capitan water to be discharged at Carlsbad Springs (Hiss, 1976, p. 259). Apparent velocity can be calculated using the formula

$$V = \frac{K}{\Theta}\frac{dh}{dl}$$

where

V = velocity

K = hydraulic conductivity

$\frac{dh}{dl}$ = hydraulic gradient, and

Θ = porosity (effective)

Neglecting the effects of diffusion and dispersion, the velocity ranges between 0.0005 and 0.0008 feet per day. Velocities are undoubtedly greater than these in some of the more-permeable zones in the Delaware Mountain Group.

Capitan Limestone

The Capitan Limestone was named by Richardson (1904, p. 41) for outcrops in the southern end of the Guadalupe Mountains where it consists primarily of a massive limestone that grades into recemented, partly dolomitized, reef breccia. The Capitan Limestone was deposited along the margin of the Delaware Basin in a continuous, narrow, arcuate-trending belt (Hiss 1976, p. 92) and has an average thickness of about 1,600 feet in Eddy and Lea Counties (Hiss, 1976, p. 145).

The Capitan Limestone, which occurs in the subsurface about 10 miles north of the proposed nuclear-waste disposal site, has the largest yield of any aquifer in the study area and it strongly affects the regional ground-water flow system.

The Capitan aquifer is recharged by slow percolation of water through the shelf and basin aquifers such as the Delaware Mountain Group and by direct infiltration on or near outcrops. Hiss (1976, p. 198) calculates that the hydraulic conductivity of the Capitan aquifer along the western margin of the Central Basin platform in Texas and New Mexico ranges from 1 to 25 ft/d. The average hydraulic conductivity for the aquifer in most of southern Lea County and east of the Pecos River valley at Carlsbad is about 5.0 ft/d. The hydraulic conductivity in the Capitan aquifer west of the Pecos River at Carlsbad, however, appears to be several orders of magnitude larger (Hale, 1945a and 1945b).

Average values of the coefficient of transmissivity reported by Hiss (1976, p. 199) east of Carlsbad around the northern and eastern margins of the Delaware Basin to the Pecos-Brewster County boundary in Texas range from 10,000 ft^2/d in thick sections to 500 ft^2/d in less-permeable incised submarine canyons.

In the aquifer, Capitan Limestone water is under water-table conditions southwest of the Pecos River at Carlsbad, but to the north and east the aquifer is artesian. Hiss (1976, p. 269) indicates that water entering the Capitan Limestone in the Guadalupe Mountains moves northeastward toward Carlsbad (fig. 4) where most of the water discharges into the Pecos at Carlsbad Springs. Hiss (1976) concludes that a deep, incised submarine canyon near the Eddy-Lea county line forms a hydraulic restriction that constrains the eastward movement of water in the aquifer from the vicinity of the Pecos River. Apparently there is little movement of water between the Pecos River and the Eddy-Lea county line. East of the hydraulic restriction, there appears to be an increase in the rate of head decline. The eastward gradient is caused primarily by the large withdrawals of water for oil-field water flooding in eastern New Mexico and west Texas.

Castile Formation

The Castile Formation, as originally described by Richardson (1904), consisted of thick anhydrite and salt units between the Delaware Mountain Group and the Rustler Formation. Lang (1935) divided the Castile into two formations, the anhydrite-rich Castile below and the salt-rich Salado above.

The Castile Formation lies conformably on the underlying Delaware Mountain Group. It is an evaporite sequence composed primarily of anhydrite and gypsum interbedded with halite and minor amounts of sandstone and limestone. The thickness varies between 1,300 and 2,000 feet (Hendrickson and Jones, 1952, p. 21). The Castile includes a basal limestone (near the basin margin), a lower laminated anhydrite, and an upper massive anhydrite (Hiss, 1976, p. 98). Solution has removed the halite from the Castile on the western and southwestern side of the basin (Maley and Huffington, 1953, p. 543); the salt thins or disappears to the north and east along the basinward margin of the Capitan Limestone (Hiss, 1976, p. 99).

The low hydraulic conductivity of the Castile impedes the flow of ground water from the Capitan aquifer to the Castile (Bjorklund and Motts, 1959, p. 122). Appreciable amounts of water occurs in the Castile only within weathered zones of outcrops along the western side of the Delaware Basin (Bjorklund and Motts, 1959, p. 123). Local cavernous zones near the outcrop serve as ground-water reservoirs from which wells may withdraw water for stock and domestic use. Water in the Castile contains large concentrations of dissolved solids.

No other areas were known to have water wells tapping the Castile at the time of the Project Gnome investigation (Cooper, 1971, p. 16). Isolated pockets of brine and associated hydrogen-sulfide gas, however, have been encountered locally in the Castile by various oil-drilling companies.

Salado Formation

The Salado Formation, differentiated from the Castile by Lang (1935), is composed primarily of rock salt in thick seams interbedded with anhydrite, polyhalite, and glauberite. The Salado conformably overlies the Castile Formation and laps extensively over the back reef.

C. L. Jones (in Jones, Cooley, and Bachman, 1973, p. 14) describes three divisions within the Salado: the lower member, the McNutt potash zone, and the upper member. The lower member consists of approximately 1,000 feet of thick, clayey halite seams interbedded with thin seams of anhydrite and polyhalite. Economically important potash minerals are not common in this member. The lithology of the McNutt potash zone, while similar to the clayey halite of the lower member, includes sylvite and langbeinite, two important potash minerals. The thickness of the McNutt ranges from 300 to 483 feet. The upper member is also composed of clayey halite interbedded with some minor anhydrite and polyhalite. Potash ores are not present except in minor amounts. Most of the halite has been removed from this unit west of the Pecos River (Hendrickson and Jones, 1952, p. 22). Leached zones consist of gypsiferous clays and fine-grained silt and sandstone. The thickness ranges from 150 feet on the western side of the Delaware Basin to as much as 590 feet on the south (Jones, Cooley, and Bachman, 1973, p. 19). The Salado salt beds grade comformably into the sandstone beds of the lower part of the Rustler Formation.

Saturated brine and nitrogen-gas filled pockets exist within the halite of the Salado (Jones, Cooley, Bachman, 1973, p. 12); no wells are known to produce water from the Salado. The lack of permeability in the salt, as seen in local potash mines, suggests that little or no fluid is present in the Salado Formation (Hendrickson and Jones, 1952, p. 22).

Evaporite residuum

Halitic clay and sand residues occur where ground water has dissolved the Upper Permian evaporites. In the Carlsbad area along the Pecos River and to the west, these clays, known locally as red beds, form dense, undifferentiable "rubble zones" (Bjorklund and Motts, 1959, p. 121). Bjorklund and Motts suggest that this clay residue has slowed ground-water infiltration and subsequent salt removal.

A brine aquifer occurs in the residuum at the Salado-Rustler contact underlying Nash Draw, and southwestward to a few miles beyond the Pecos River. The same structural controls may have been influenced both topographic development and ground-water movement resulting from dissolution and erosion (Robinson and Lang, 1938, p. 86). This brine aquifer extends from the recharge area northwest of Nash Draw to its termination in the vicinity of Malaga Bend. The aquifer ranges in width from 2 to 10 miles and has a length of approximately 30 miles (fig. 5). Water penetrates the overlying units through fractures and solution zones in the recharge area and moves southward along the top of salt, thereby increasing in chloride concentration (Robinson and Lang, 1938, p. 88) until it discharges into the Pecos River at Malaga Bend.

Theis and Sayre (1942) calculated discharge from the brine aquifer into the Pecos River at Malaga Bend to be about 200 gpm. Hale (in Hale, Hughes, and Cox, 1954, p. 22) calculated a value of transmissivity of 8,000 ft^2/d from aquifer tests in the area between Malaga Bend and Laguna Grande de la Sal. The potentiometric gradient estimated during this study was 1.4 ft/mi. Assuming an effective porosity of 0.2 and an average thickness of 50 feet, the rate of movement of the brine would be 0.2 ft/d (Hale and Clebsch, 1958, p. 11). With an average width of 5 miles, a transmissivity of 8,000 ft^2/d, and a gradient of 1.4 ft/mi, the volume of water passing a given cross section would be on the order of 56,000 ft^3/d (Hale, Hughes, and Cox, 1954, p. 23). This is a somewhat larger value than the 200 gpm or 38,500 ft^3/d calculated by Theis and Sayre for discharge at Malaga Bend.

Rustler Formation

The Rustler Formation, named by Richardson (1904), is the youngest unit in the Ochoan evaporite sequence and marks the final invasion of the Permian sea into the Delaware Basin.

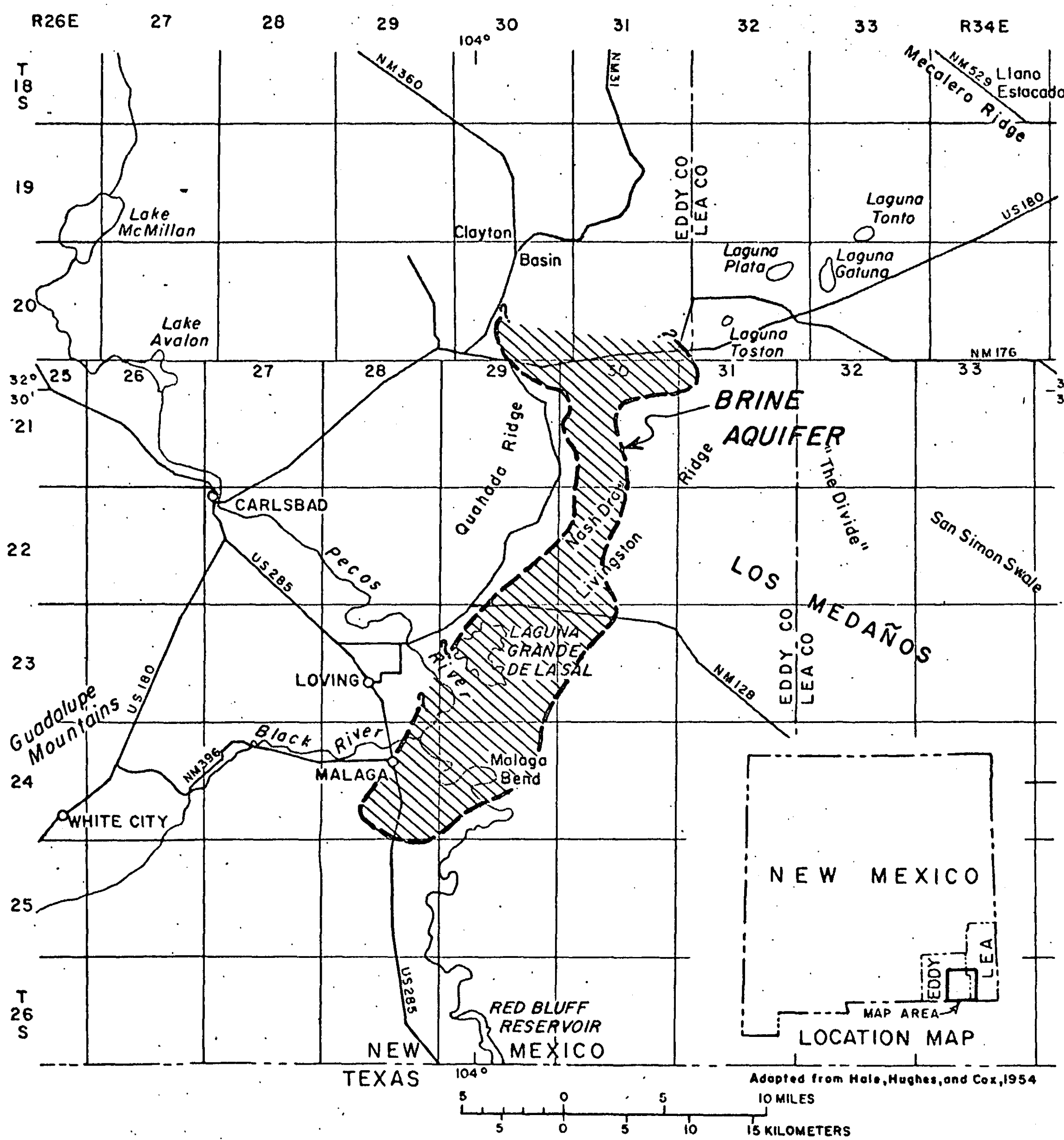


Figure 5.--Areal extent of brine aquifer.

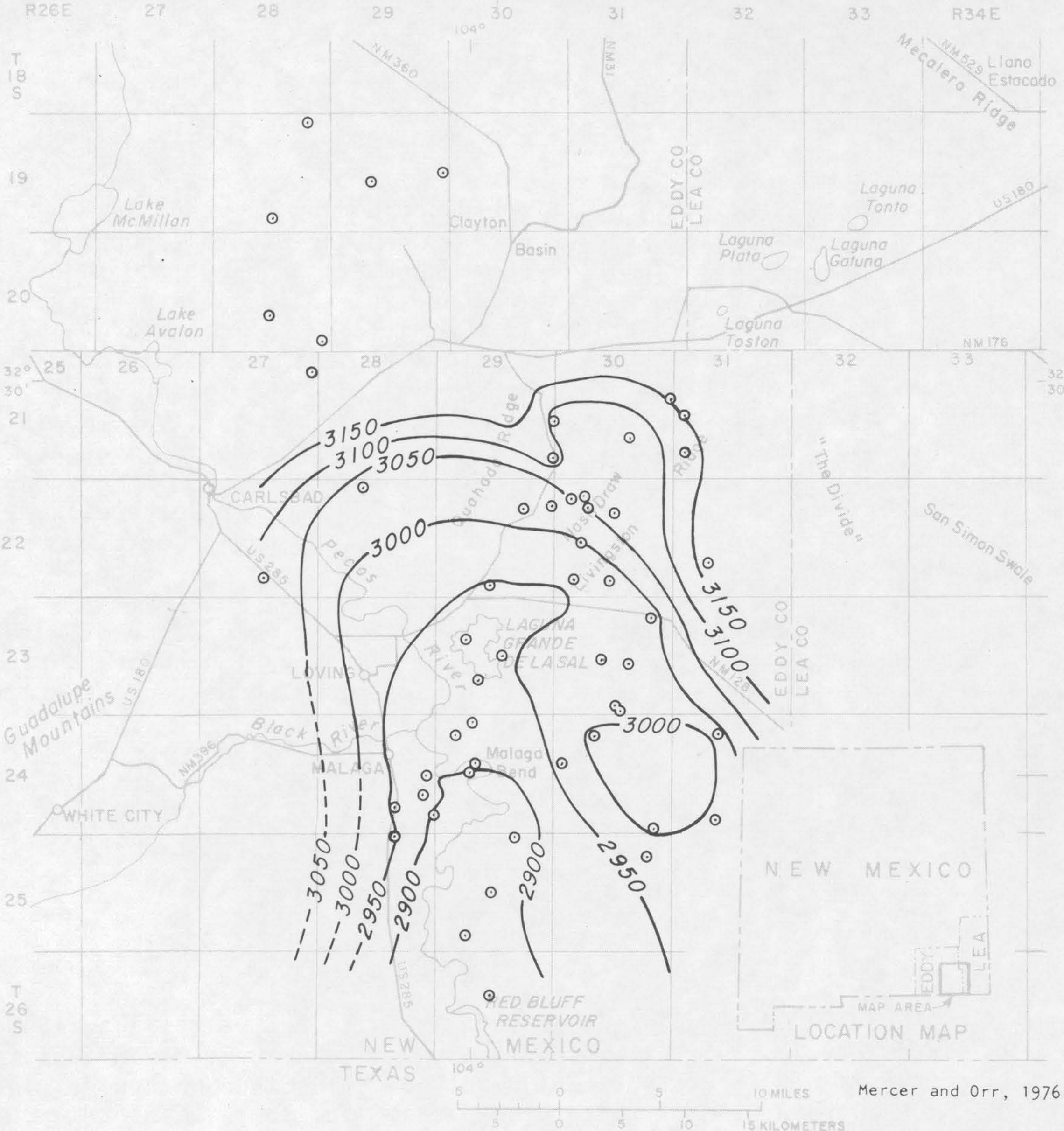
The Rustler contains anhydrite, gypsum, red beds, dolomite, limestone, and halite. The lower Culebra Dolomite Member and the upper Magenta Member are distinctive stratigraphic marker beds that persist throughout the Delaware Basin (Adams, 1944, p. 1614). The thickness of the Rustler generally ranges from 200 feet in the western part of the Delaware Basin to 600 feet in the eastern part.

The structure of the Rustler Formation is slightly undulating. Solution and collapse have affected the Rustler to depths of 200 to 300 feet and locally (as under Nash Draw) to greater depths (Cooper, 1971, p. 6). Thus, the collapse has caused bedding in the less soluble zones to be slumped and highly brecciated. In Nash Draw there are places where solution has completely removed the intervening beds and the Magenta lies on the Culebra Member. The Rustler contact with the underlying Salado is gradational and appears conformable where solution has not taken place.

Although the Culebra Dolomite Member of the Rustler Formation is the most persistent aquifer in the area, yields of water from the Culebra vary considerably from place to place. Cooper (1971, p. 8) suggests that the variability of yields is related to the size and number of fractures and openings in the dolomite which, in turn, could be related to the thickness of overlying formations. In the upper part of Nash Draw, the dolomite is near the surface, and is reported to yield as much as 700 gpm. East of Nash Draw, where the dolomite is covered with Triassic and younger rocks, yields are very small (Cooper, 1971, p. 8).

Quantitative values for hydraulic properties of the Rustler are variable. Data are generally limited, primarily originating from studies related to Malaga Bend brine disposal and Project Gnome area just south of the Los Medaños area. Aquifer-performance tests of test holes drilled in support of Project Gnome yield an average hydraulic conductivity of 16 ft/d and an average effective porosity of 10 percent. Transmissivity of the Culebra Dolomite Member was calculated to be approximately 500 ft^2/d (Cooper, 1971, p. 10). Cooper (1971, p. 11) reports average rates of movement to be about 0.5 ft/d.

Water in the vicinity of the Project Gnome site moves westward toward the Pecos River. Movement in the Rustler near Los Medaños is westward toward Nash Draw and then southwestward toward the Pecos River (fig. 6). North and south of Nash Draw, potentiometric contours indicate movement to the south and southwest. Water on the west side of the Pecos River appears to move through the Rustler Formation and the alluvium in an easterly direction toward the Pecos. The two units are closely connected in this area.



EXPLANATION

⊙ Well producing water from Rustler Formation

3000 — Potentiometric contour showing altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 50 feet. Datum is mean sea level.

Sources of data:
Hendrickson and Jones, 1952; Hale and others, 1954; Cooper, J. B., 1962; Jones and others, 1973

Figure 6.--Potentiometric surface of the Rustler Formation, 1952 through 1973.

Dewey Lake Red Beds

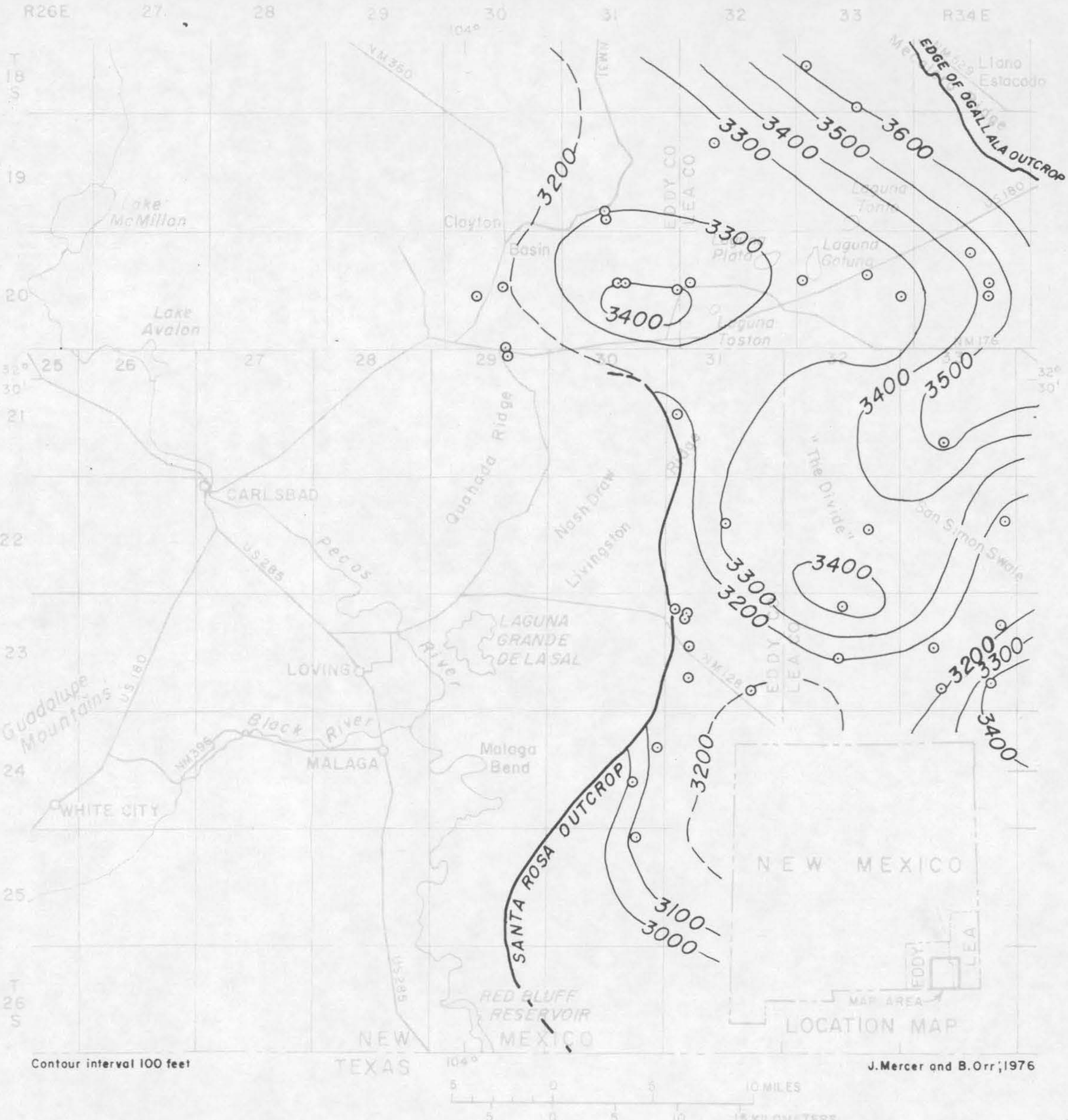
The Dewey Lake Red Beds, first described by Page and Adams (1940), conformably overlie the Rustler Formation; they are the youngest deposits of the Ochoan Series. The Dewey Lake consists of about 200 to 600 feet of reddish-orange siltsone with mudstone and sandstone stringers. It differs from other Ochoan rocks in that it does not contain evaporites. The Dewey Lake crops out in low bluffs along the north end and east side of Nash Draw. Other near-surface parts of the formation are mantled by blankets of dune sand and caliche. Jones (1954, p. 107) indicates that the Dewey Lake Red Beds form a protective cover that slows solution of underlying evaporites in the area of Los Medaños. The end of deposition of the Dewey Lake Red Beds marked the close of the Permian time in the Permian Basin and the beginning of a period of erosion and nondeposition.

Very little information is available on the occurrence of water in the Dewey Lake Red Beds; however, its lithology indicates that it would be a poor aquifer. Locally the sandstone lenses could contain water but the supply probably would be small.

Triassic rocks

Santa Rosa Sandstone

The Santa Rosa Sandstone of Late Triassic age, first described by Darton (1922), is the lower unit of the Dockum Group. The upper unit, the Chinle Formation, conformably overlies the Santa Rosa along the northeastern side of the project area. The Santa Rosa Sandstone consists of pink-to-gray, fine to medium-grained, poorly sorted sandstone that is crossbedded, and interbedded with shaly siltstone and conglomerate. According to Nicholson and Clebsch (1961, p. 56) the thickness ranges from about 140 feet to 300 feet. The Santa Rosa Formation, which dips gently eastward except in areas of collapse, crops out on Livingston Ridge and northwest of Nash Draw (fig. 7).



EXPLANATION

⊙ Well producing water from Triassic rocks.

3000 - - - Potentiometric contour showing altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 100 feet. Datum is mean sea level.

——— Edge of Santa Rosa outcrop

Sources of data:
Hendrickson and Jones, 1952; Hale and others, 1954;
Cooper, J.B., 1962; Jones and others, 1973;
Lyford, written commun., 1973

Figure 7.--Potentiometric surface of the Santa Rosa Sandstone, 1952 through 1973.

Ground-water recharge to the Santa Rosa Formation is from precipitation on the outcrop, percolation through sand dunes, and infiltration from the overlying Ogallala Formation to the east (Nicholson and Clebsch, 1961, p. 56). Areas of recharge are indicated by mounds and ridges on the potentiometric surface (fig. 7). A potentiometric high underlies the outcrop areas north of Nash Draw and along Livingston Ridge. The potentiometric surface dips steeply southwest away from the Ogallala and a very broad ridge trends southwest across "The Divide." Troughs within the potentiometric surface indicate discharge zones. These potentiometric lows occur near the Eddy-Lea county line east of Clayton Basin, and in the San Simon Swale. Nicholson and Clebsch (1961, p. 57) suggest that this discharge is downward into underlying Permian rocks through collapse zones in which vertical permeability has increased. In general, ground water moves to the south and southwest where it ultimately discharges into the Pecos River.

Wells completed in the Santa Rosa Formation have low yields with specific capacities of 0.14-0.2 gpm per foot of drawdown (Nicholson and Clebsch, 1961, p. 57); the formation porosity is about 13 percent. According to Cooper (1962, p. 27), movement of ground water in the Santa Rosa is primarily along joints and bedding planes. Velocities on the order of 0.3 ft/d near Los Medaños have been estimated by Hale and Clebsch (1958, p. 14).

Chinle Formation

The Chinle Formation, described by Darton (1922), conformably overlies the Santa Rosa Sandstone. The Chinle is dominantly reddish-brown shaly mudstone interbedded with greenish-gray mudstone and minor lenses of sandstone and conglomerate. It ranges in thickness from about 0 near the Eddy-Lea County line to as much as 800 feet in the area north of San Simon Swale.

Data on the occurrence of water in the Chinle Formation is sparse; however, its lithology indicates it would yield very little water.

Tertiary and Quarternary geology

Late Cenozoic history

The following summary of the late Cenozoic surficial history of Los Medaños and vicinity is based on a comprehensive study of the area by Bachman (1973). Late Tertiary regional uplift and eastward tilting elevated the western section of the Permian evaporites, exposing them to dissolution and subsidence and creating new patterns of ground-water movement. Erosional forces carved a pediment-like surface on which the fluvial fans of the Miocene Ogallala Formation were deposited. Eolian activity reworked Ogallala sediments, developing a widespread soil profile and caliche known today as the "caprock" of the Llano Estacado. During the late Pliocene and early Pleistocene, longitudinal dunes developed as a result of westerly and northwesterly prevailing winds. Etching and thinning of the caliche caprock between dunes generated parallel lineations or swales upon the Llano Estacado. Erosion and coalescing of subsided areas removed Ogallala sediments and entrenched the Pecos and San Simon drainages. Pleistocene solution and subsidence deepened the San Simon, Nash Draw, and Clayton Basin depressions in which thick deposits of Cenozoic fill were laid down.

Tertiary and Quaternary rocks

Tertiary and Quaternary deposits include the Ogallala Formation of Miocene age, the Gatuna Formation of Pleistocene age, and sands, caliche, and alluvium of Holocene age.

The Ogallala Formation underlies the High Plains (Llano Estacado) of eastern New Mexico and west Texas. It is present about 15 miles northeast of the report area (fig. 2). There are no definite remnants of the Ogallala west of easternmost Eddy County, but isolated small gravel deposits in the Pecos valley and on high parts of the Guadalupe Mountains have been interpreted as belonging to this formation (Bretz and Horberg, 1949). Even though the Ogallala is not present in the report area, it may be a source of water for recharge to the underlying Triassic rocks. Nicholson and Clebsch (1961, p. 58) report that the saturated thickness of the Ogallala ranges from 25 to 175 feet. This variability can be attributed to the very irregular Triassic surface which underlies it. Movement of water in the Ogallala is controlled to a great extent by the generally southeastward slope of the underlying red beds.

The Gatuna Formation is the oldest known Quaternary Formation in the area and is probably the thickest and least extensive. The formation varies erratically in thickness from 0 to 375 feet (Jones and others, 1973, p. 28). It is a typical bolson-type deposit filling channels and steep walled valleys cut primarily into the Dewey Lake Red Beds and the Rustler Formation. In the type section and in the vicinity of Nash Draw where the Gatuna is readily recognizable, it is overlain by a prominent caliche that marks the Mescalero surface (Bachman, 1973, p. 14).

Vine (1963, p. B31) suggested that Gatuna deposition probably followed soon after, or in part accompanied, a period of active solution in the Rustler and Salado Formations. In Nash Draw, the Gatuna is thickest where solution and subsidence have taken place and, except for very localized areas, is not present east of Nash Draw. Locally, the Gatuna Formation yields limited amounts of water to wells because the water is in isolated gravel and sand lenses. Yields are small but are usually sufficient for stock and domestic use (Cooper, 1962, p. 28). Ground-water movement is apparently restricted by the discontinuous "perched" zones. Some water probably percolates downward into Triassic sandstone or the Rustler Formation.

Alluvial deposits consisting of sand, silt, and localized conglomerate are restricted to valleys and collapse features. The most extensive deposits are along the west side of the Pecos River north of Malaga. Isolated patches of alluvium, however, occur along the Pecos throughout the southern part of the area. Thicknesses of alluvium vary considerably; but where concentrated along the river, depths generally approach 300 feet (Cooper, 1962, p. 29). Consequently, these are areas where yields are relatively high. The source of the water is primarily from the Pecos River through leakage from canals and irrigation return flow, according to Hale and Clebsch (1958, p. 19); they estimate the rate of movement of water in the alluvium to be less than 1 foot per day. They qualify this by stating that rates in solution channels within the basal conglomerate may be as much as 100 times this figure. Transmissivities vary considerably, but calculations made by Bjorklund and Motts (1959, p. 191) give an average figure of 13,600 ft^2/d.

South of Malaga, the alluvium is localized in extent and variable in thickness. The water is probably associated with and, in part, is continuous with water in the underlying Rustler Formation.

Alluvium east of the Pecos River is localized in small closed depressions. Some of these contain water, as does the playa lake of Laguna Grande de la Sal. The lake and playa deposits often yield some water, although it is generally highly mineralized.

Nash Draw and Clayton Basin contain Quaternary alluvium, but the thickest alluvial deposits occur within San Simon Swale where Bachman (1973, p. 20) reports thicknesses up to 500 feet. Ground water in the San Simon alluvium may be derived from discharge from the Santa Rosa Sandstone (fig. 7).

Summary of hydrologic conditions

Delaware Mountain Group

1. Average hydraulic conductivities are approximately 0.16 ft/d and average porosities are on the order of 15.65 percent. With an assumed saturated thickness of 3,000 ft, transmissivities are 50 ft^2/d. The potentiometric gradient is between 25 and 40 ft/mi, and ground-water velocities are from 0.0005 to 0.0008 ft/d.
2. Direction of movement is to the north and northeast.
3. Discharge is into the Capitan Limestone and associated back-reef rocks.
4. The three formations comprising the Delaware Mountain Group are assumed to be hydraulically connected.

Capitan Limestone

1. Hydraulic conductivities of the Capitan range from 1 to 25 ft/d and average about 5 ft/d. Average values of transmissivity are estimated to range from 10,000 ft^2/d in thick sections to 500 ft^2/d in less-permeable zones.
2. Water movement in the Capitan west of the Pecos is northeastward toward the river. Water movement east of the Pecos is difficult to ascertain, but it probably would be insignificant because of a hydraulic restriction near the Eddy-Lea county line.
3. Northwest of the report area, recharge is by slow percolation of water from the back-reef aquifers associated with the Capitan Limestone and by direct infiltration at or near the outcrop. Discharge is into overlying alluvium or into the Pecos at Carlsbad Springs, and eastward into the back-reef aquifers in Lea County. In eastern New Mexico and west Texas large volumes of water are removed from the Capitan for water-flooding in the oil fields.

Castile Formation

1. Few data are available on the hydraulic properties of the Castile.
2. Water occurs in areas of weathered outcrops and as brine pockets.
3. Recharge is from precipitation and infiltration on outcrop areas.
4. Highly mineralized water derived from localized cavernous reservoirs in the weathered outcrop is used for stock and domestic purposes. Brine pockets and associated hydrogen sulfide occur in the Castile. The Castile serves as a confining bed for the underlying Delaware Mountain Group.

Salado Formation

1. No wells are known to produce water from the Salado. Isolated brine and nitrogen-gas pockets have been encountered.

Evaporite residuum

1. Surficial discharge to the Pecos River from the brine aquifer underlying Nash Draw is about 200 gal/min, transmissivity is 8,000 ft^2/d, potentiometric gradient is 1.4 ft/mi, and the rate of flow is 0.2 ft/d.
2. Water in the brine aquifer that is oriented along Nash Draw flows south and southwest.
3. the recharge area is the outcrop of the Rustler Formation northwest of Nash Draw; discharge is at Malaga Bend into the Pecos River.
4. The brine aquifer and the topographic expression of Nash Draw developed along the same structural control. The low permeability of the residuum generally retards continued infiltration and solution within the salt.

Rustler Formation

1. Water-well yields range from less than 1 gal/min to about 700 gal/min; transmissivities likewise range from near 0 to 500 ft^2/d; for the Project Gnome site (fig. 1), porosities of 10 percent and average permeabilities of 16 ft/d have been calculated, with an average rate of movement of 0.5 ft/d.
2. Ground-water movement is to the west and south toward the Pecos River.
3. Recharge on the outcrop and in Nash Draw is from precipitation and percolation through collapse features.
4. Porosity and permeability are related to the degree of fracturing and extent of solution within the formation, and decrease with increasing thicknesses of overlying rocks. The Culebra Dolomite Member, the principal water-bearing unit, porvides water to stock wells within Nash Draw.

Dewey Lake Red Beds

Few data are available. Siltstone and claystone of low permeability form confining beds for underlying and overlying units. Water occurs in sandstone lenses; generally, the Dewey Lake Red Beds are a poor aquifer.

Santa Rosa Sandstone

1. Permeabilities have been estimated at 13 percent and specific capacities of between 0.14 and 0.2 (gal/min)/ft drawdown have been calculated; rates of movement are on the order of 0.3 ft/d; otherwise little quantitative data are available.

2. Movement, in general, is to the south and southwest, but local gradients are toward subsidence features.

3. Recharge is from precipitation and infiltration from runoff on the outcrop and overlying sand dunes, and by inter-aquifer flow from the Ogallala Formation to the east. Discharge occurs vertically through collapse features into the underlying Permian rocks as well as into the Pecos River to the southwest.

4. Low permeabilities result in low yields to wells; movement is along bedding planes and joints.

Chinle Formation

Few data are available on the occurrence of water in the Chinle Formation; however, its lithology indicates it would yield very little water.

Ogallala Formation

1. Saturated thickness ranges from 25 to 175 feet.

2. Movement of water in the Ogallala is controlled to a great extent by the generally southeastward slope of the underlying red beds. The Ogallala may be a source of recharge for the Santa Rosa Sandstone.

Gatuna Formation

Thickness varies from 0 to 375 feet. Water occurs in discontinuous sand and gravel lenses. Well yields are small and ground-water movement is restricted. The Gatuna is a possible recharge medium for underlying aquifers.

Alluvium

1. Rate of movement is estimated to be less than 1 ft/d except in solution channels where it may be 100 times greater. An average transmissivity has been calculated at 13,600 ft^2/d. The alluvium may be as much as 300 feet thick.

2. Water in alluvium along drainage channels moves generally in the direction of surface flow.

3. Recharge is from the Pecos River and from precipitation, runoff, and flow from underlying aquifers.

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